Integrated Carbon Capture & Storage for Kansas

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University of Kansas

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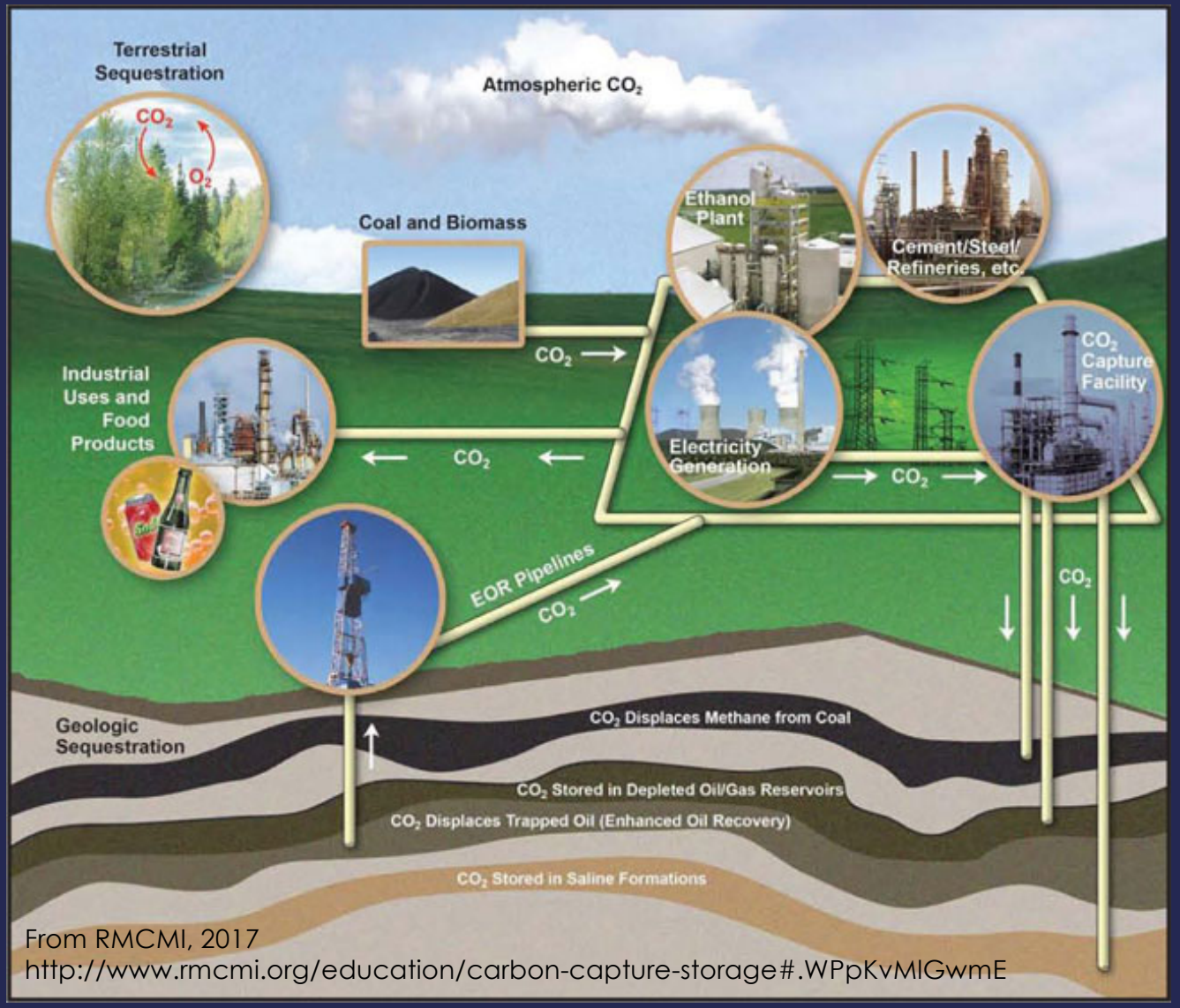
Outline

- Carbon Capture and Storage (CCS)
- Kansas resources and improving the economics of CCS
- Dept. of Energy – CarbonSAFE Program
- Integrated CCS for Kansas (ICKan)
  - Scope
  - Team & participants
  - Technical & nontechnical evaluations
- Next phase of research
- Summary

Carbon Capture & Storage (CCS)

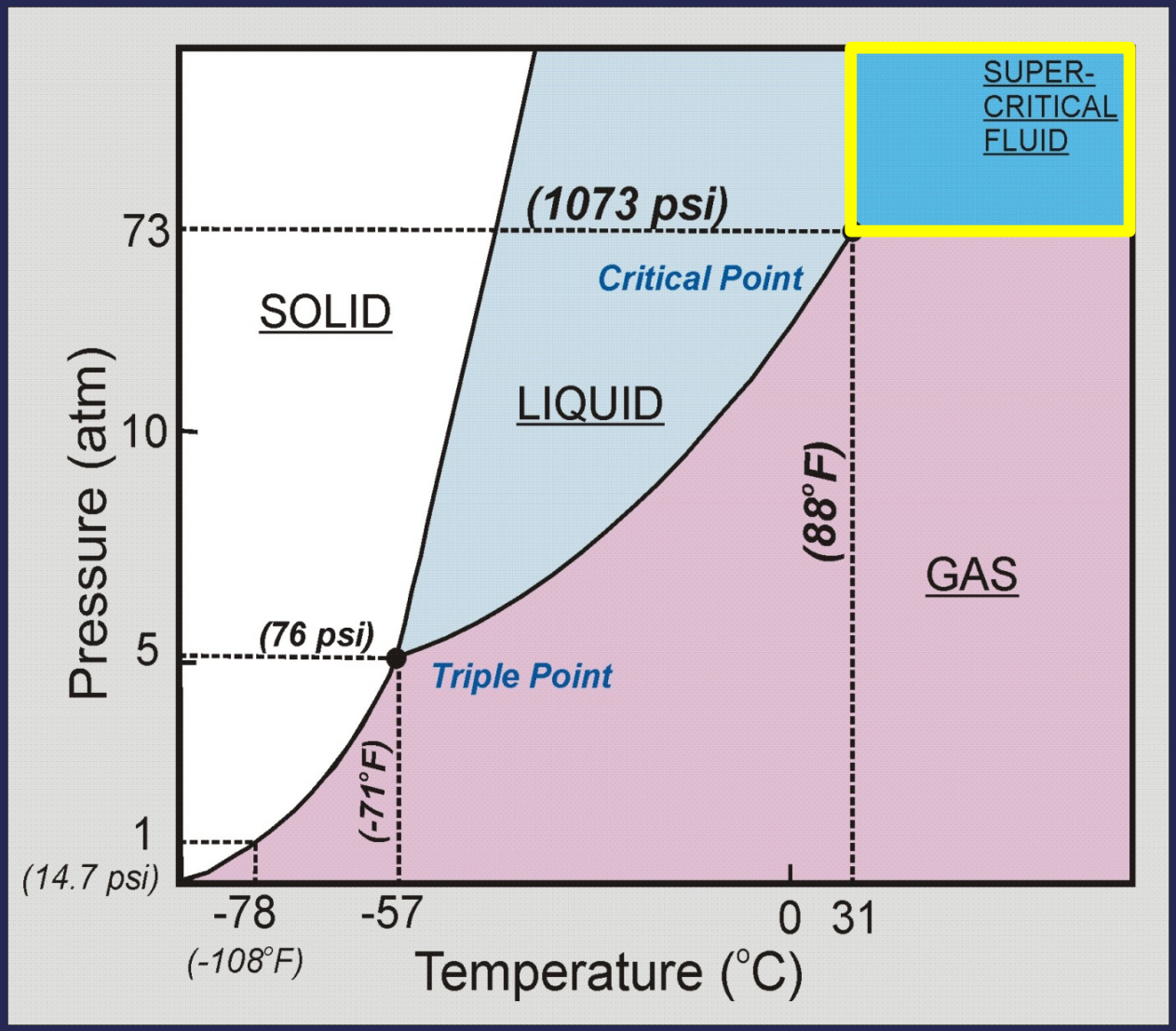
- Public demand for clean energy is growing
- Policies to reduce CO_2 emissions
- How do we extend our fossil energy investments?



From RMCMI, 2017
http://www.rmcmi.org/education/carbon-capture-storage#.WPpKvMlGwmE

CO_2 – the *magical* fluid

CO2 Phase Diagram



Modified after Condren www.cbu.edu/~mcondren/CO2_phase_diagram.jpg

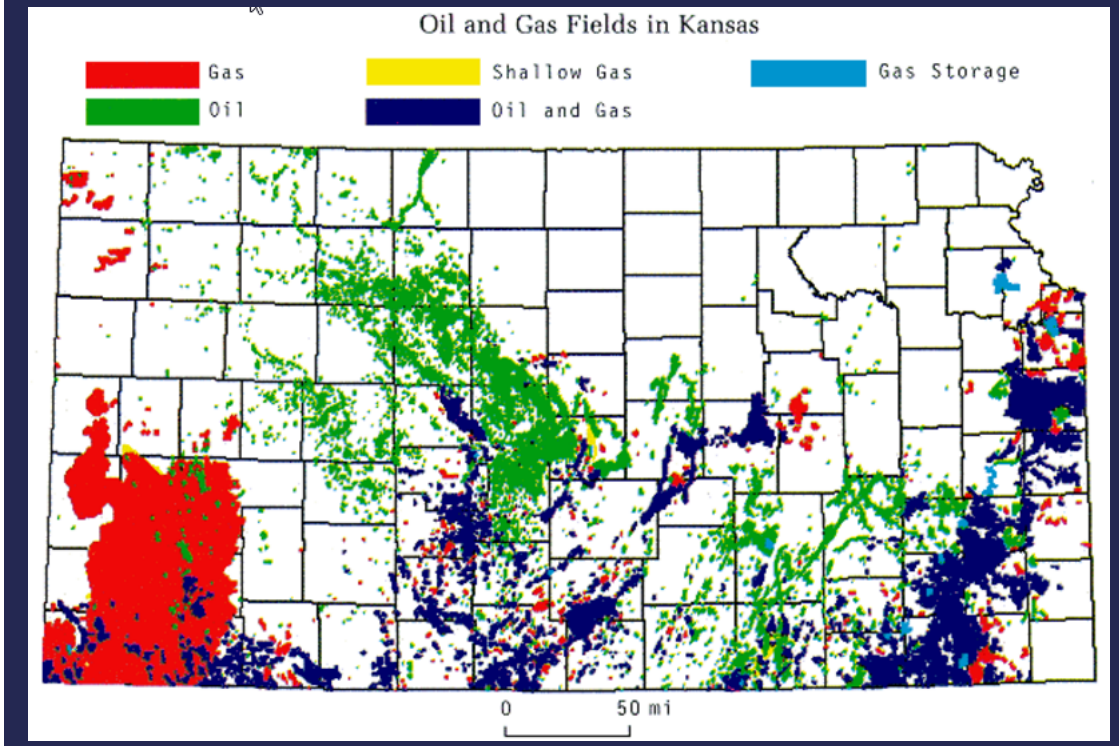
- Supercritical CO_2
- Properties change:
  - Dense like liquid
  - Viscosity of a gas
  - Occupies less volume

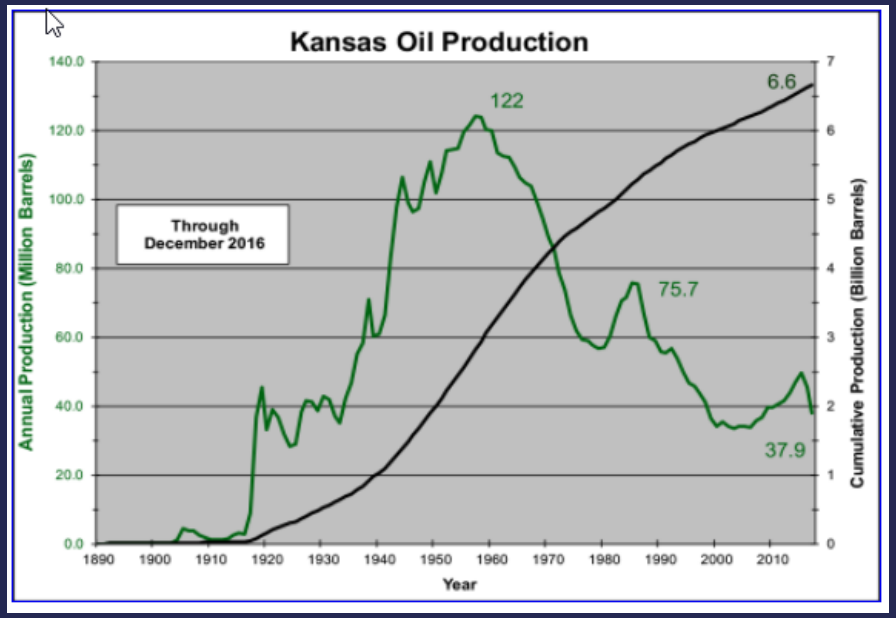
Hindrances to implementation

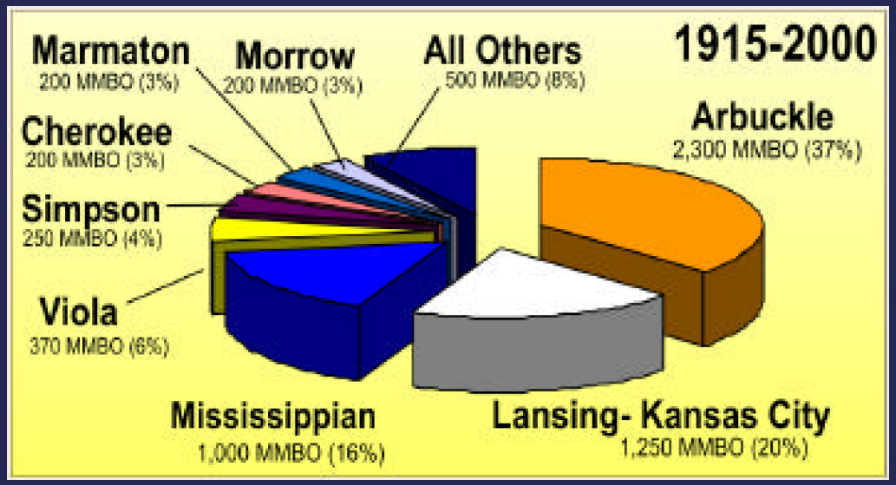
- Capture at power plants is expensive
  - Additional equipment, O&M, parasitic loads
- Suitable storage sites are not in proximity of CO_2 sources
  - CO_2 transportation costs
- Identification and permitting of geologic storage sites
  - Additional time and cost
- Need to improve the economics!

Kansas CO_2-EOR Potential

- Oil-rich, but no appreciable CO_2
  - 6.6 Billion barrels; Now at 36 mmbo/yr
- Additonal 10 mmbo/yr possible
  - Most prolific are LKC and Arbuckle

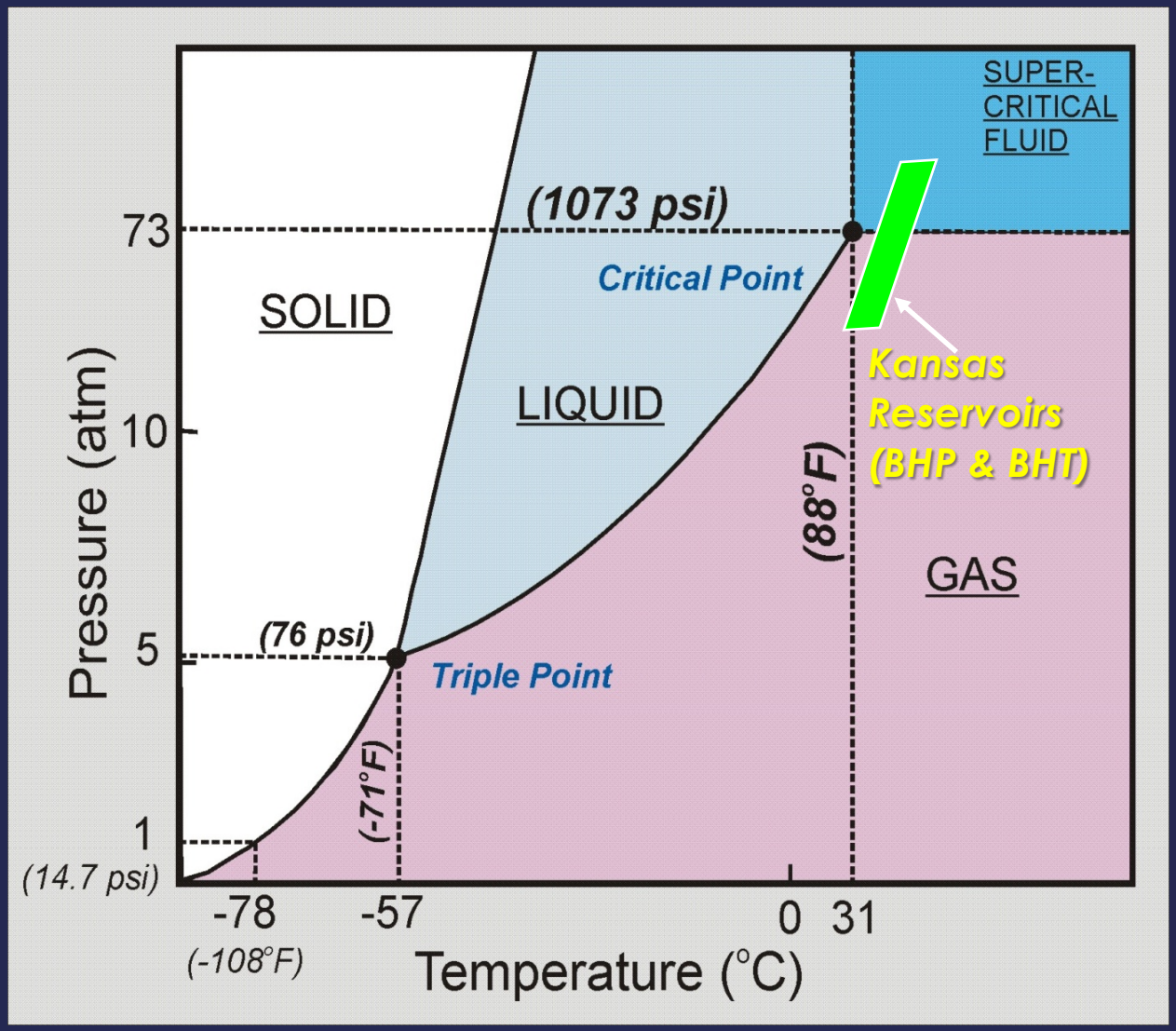






Kansas Reservoir Conditions

CO2 Phase Diagram



Modified after Condren www.cbu.edu/~mcondren/CO2_phase_diagram.jpg

- Many Kansas fields and reservoirs have suitable PT conditions:
  - 400 psi and 85F at 1000 ft
  - 1600 psi and 125 F at 6000 ft

The Big Picture

- From the Midwest Governor's Association and ARI (2009)
- Kansas holds **>750 million barrels** of technical CO_2-EOR potential.
- Kansas has the largest oil resources in the MGA region.

Basin	EOR potential (Mil bbl)	Net CO_2 Demand (MMT)	Direct Jobs Created
Illinois/Indiana	500	160 – 250	1,550 – 3,100
Ohio	500	190 – 300	1,550 – 3,100
Michigan	250	80 – 130	800 – 1,800
Kansas	750	240 – 370	2,300 – 4,600
TOTALS	**2,000**	**670 – 1,050**	**6,200 – 12,400**

Byrnes et al., 1999 (Kansas Geological Survey)
250 to 1,000 million barrels

"CO_2 Ready" EOR Fields

	CO2 EOR Ready Level	Inject. Rate (Mt/yr)	CO2 Stored (Mt)	Primary & Secondary (mmbo)*	CO2 EOR (mmbo	Basis for Estimate
Shuck	1	0.4	1.5	7.9	3.6	DE-FE000256
Cutter	1	0.5	1.3	5.4	2.8	DE-FE000256
N Eubank	1	0.6	1.5	7.4	4.6	DE-FE000256
Pleasant Prairi	1	0.3	0.5	4.7	2.2	DE-FE000256
Hall Gurney	1	1	11.3	62.5	26.8	DE-AC26-00BC15124 **PILOT** & C12 Ener
Trapp	2	0.5	4.3	31.3	10.3	KGS reports
Wellington	1	0.6	2.2	16.2	5.3	DE-FE0002056 and **PILOT**
		3.9	**22.8**	**135.4**	**55.7**	

** P&S production is for portion of field that could be flooded*

Quality of Kansas CO_2 Sources

Kansas:

- Total 72.8 Million Metric Tons/Year
- Electric Power 37.2 Million Metric Tons/Year
- Highest purity is lowest volume

	Quality	Purity*
Ethanol	High	99%
Ammonia	High	99%
Coke Gasification	High	99%
Meth. Reform.	Moderate	65%
Cement	Low	20%
Power Plants	Low	8-12%

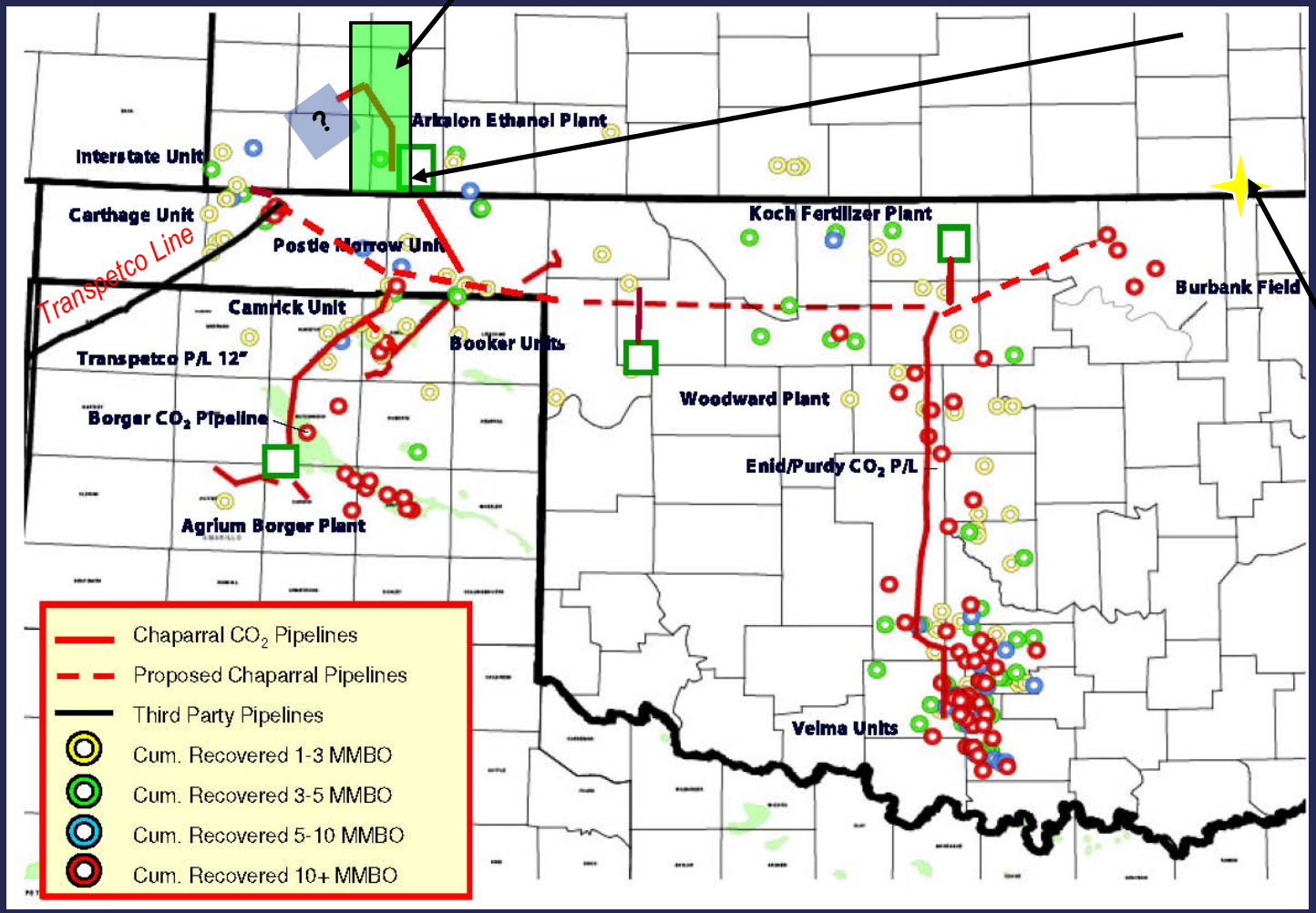
** dry weight %*

Market for CO_2 in Kansas

1. High purity CO_2 sources are being utilized
2. CO_2 from two of four viable 50mg/yr plants used for EOR
3. One was under contract until KCC denied pooling application in 2015
4. Single large fertilizer plant source (CVR) used for EOR

CO_2 Infrastructure Needs

Red solid lines currently deliver CO_2 from ethanol and fertilizer plants to oil fields



Chapparal moving CO_2 from Liberal since 2009

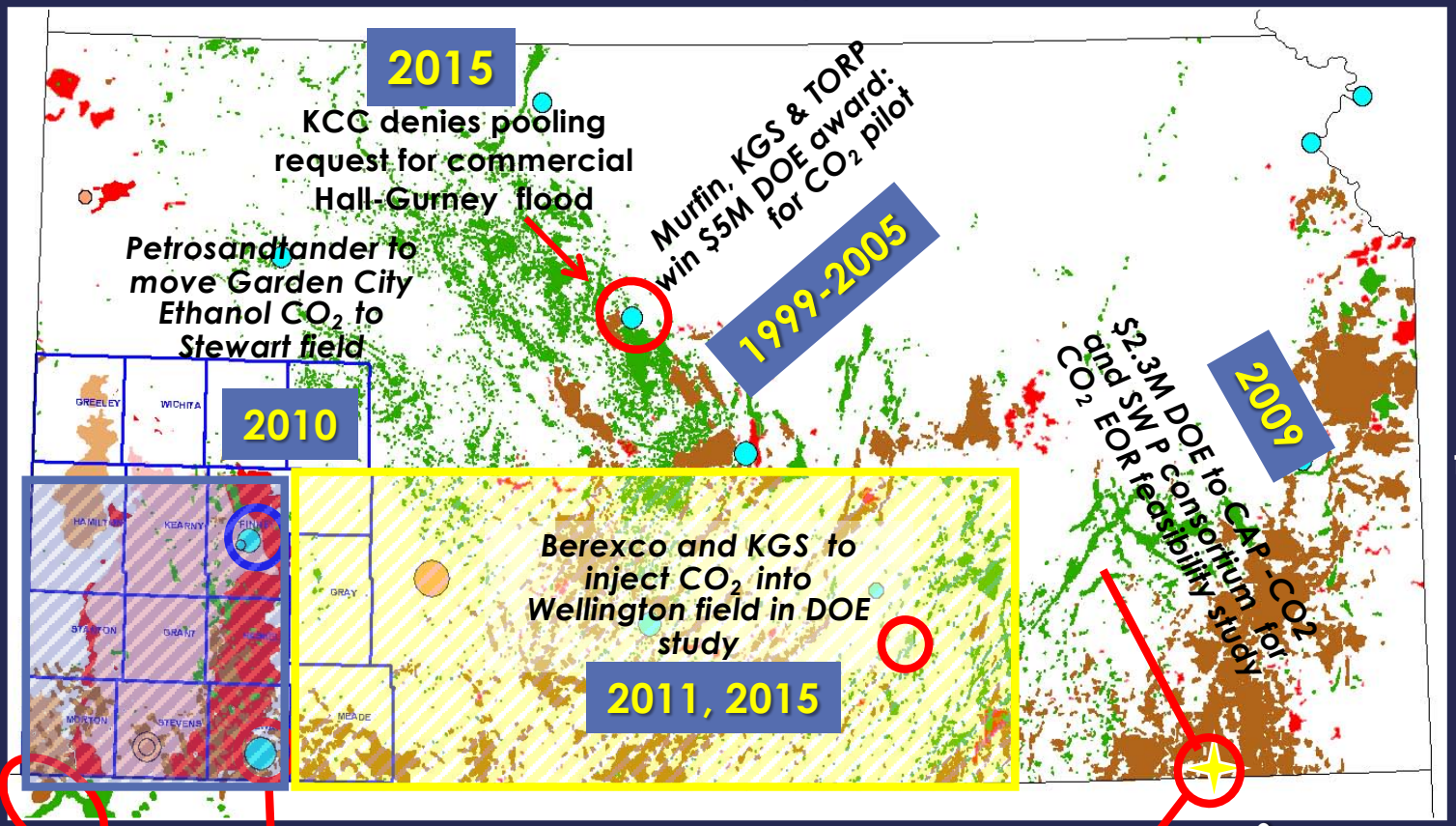
3/29/2011 Chapparal contract for 2000 tons/day CO_2 from CVR

Modified From: Chaparral Energy presentation at JP Morgan conference (March 2010)
http://www.chaparralenergy.com/pressreleases/JP%20Morgan%20HY%20Conf%20March%202010.pdf

CO_2 EOR and CCUS in Kansas

Kansas Ethanol Plants (2008)

Blue – active, Tan - planned



KGS and five industry partners expand CCS & EOR study with $5M DOE grant

2010

2016

KGS and industry partners land $1.5M for Phase I in DOE CarbonSAFE program

Transpetco builds CO_2 pipeline from Denver City to Postle Field

1997

Chapparal buys Liberal Ethanol CO_2 for Okla. EOR

2009

Berexco and KGS study Arbuckle CO_2 storage potential with $5M DOE grant

2009

Chapparal and CVR ink deal for fertilizer CO_2 for EOR

2011

CarbonSAFE

- **Carbon S**torage **A**ssurance **F**acility **E**nterprise
  - DOE's Office of Fossil Energy
- Recognizes need for CCS to operate on massive scale in order achieve U.S. clean energy goals, but commerciality hindered by:
  - Lack of economic incentives for private sector
  - Identify and certify geologic storage sites
- Major goal is to develop integrated CCS storage complex
  - Constructed and permitted for operation by 2025
  - Storage of 50+ million metric tons of CO_2

4 Phases of CarbonSAFE

I. Integrated CCS Pre-Feasibility (1.5 years) - $1.2M
II. Storage Complex Feasibility (2 years) - $8-10M
III. Site Characterization (2 years) - TBA
IV. Permitting and Construction (3.5 years) - TBA

Phase I: Integrated CCS Pre-Feasibility

Goals & Objectives:

1. Form a team to identify and address technical and non-technical challenges of implementing commercial-scale CCS in Kansas
2. Perform high-level technical evaluations of the sub-basin and potential CO_2 source(s)
3. Develop a plan (strategy) to address the challenges and opportunities for commercial-scale CCS in Kansas

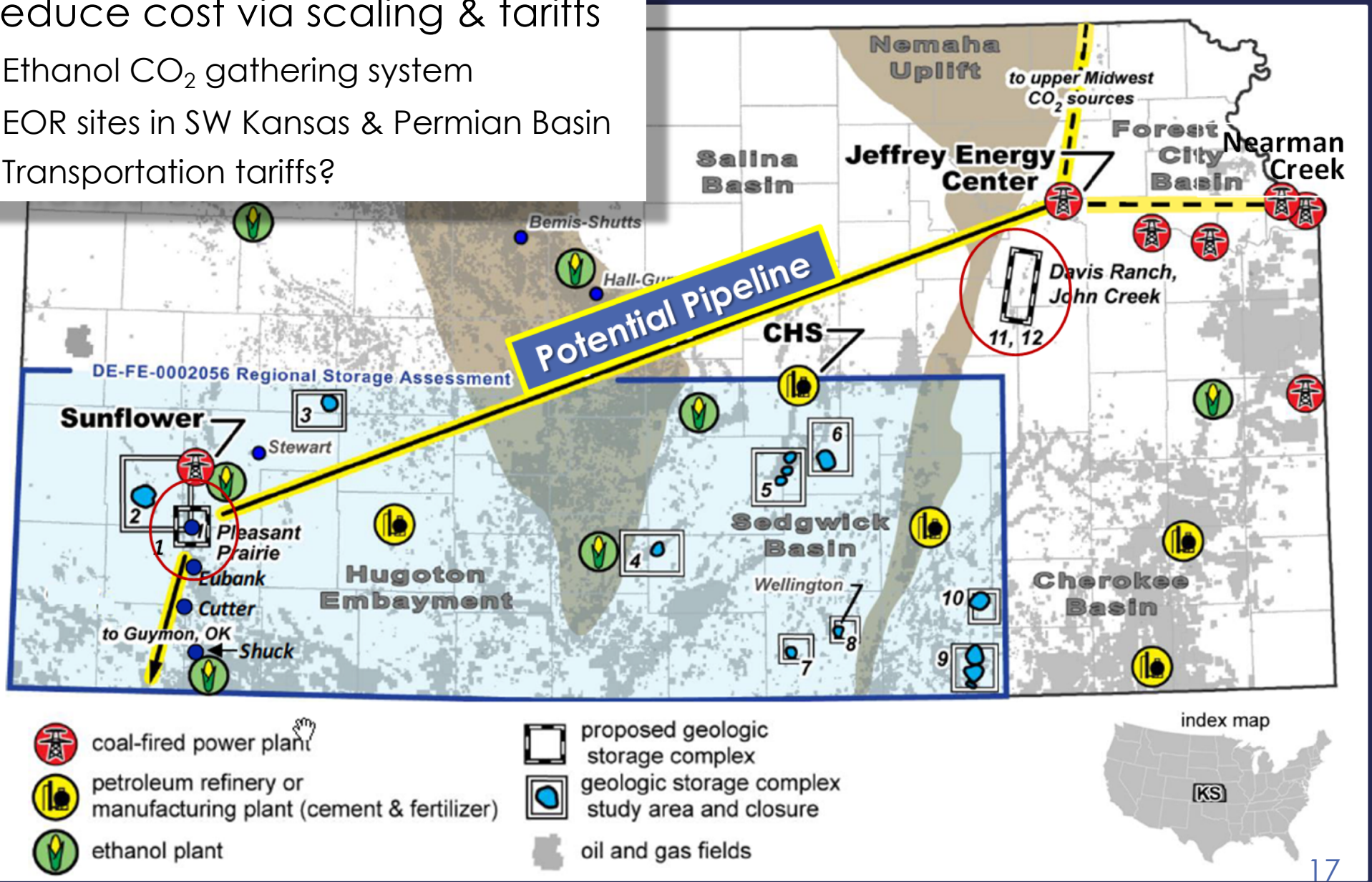
Project Overview: Base Case Scenario

- Capture 50 million tonnes CO_2 from one of three Jeffrey Energy Center's 800 MWe plants over a 20 year period (2.5Mt/yr)
- Compress CO_2 & transport 300 miles to Pleasant Prairie Field in SW Kansas.
  - Alternative: 50 miles to Davis Ranch and John Creek Fields.
- Inject and permanently store 50 million tonnes CO2 in the Viola Formation and Arbuckle Group

Jeffrey to SW Kansas

Reduce cost via scaling & tariffs

- Ethanol CO_2 gathering system
- EOR sites in SW Kansas & Permian Basin
- Transportation tariffs?



Technical Evaluations

Sub-Basinal Evaluations

Pleasant Prairie

- 170 Mt storage
- Viola & Arbuckle
- CO_2-EOR reservoirs
- Adequate data (core)
- Unitized; single operator

Davis Ranch-John Creek

- 50 Mt storage
- Simpson and Arbuckle
- Proximity to JEC
- CO_2-EOR reservoirs
- Adequate data
- Two operators

CO_2 Source Assessments

Westar Jeffrey Energy Center

- 2.16 GW &13.8 million tons of CO_2

Sunflower's Holcomb Plant

CHS McPherson Refinery

KC Board of Public Utilities

CO_2 Transportation

Pipeline

- 300 km
- Oklahoma and upper Midwest connections
- Branch connections to regional ethanol producers

Non-Technical Evaluations

Implementation Plan

Economics

- Capture & transportation economic feasibility
- Financial backing
- Financial assurance under Class Vi
- State incentives
- Federal tax policy

Legal & Regulatory

- Property rights
- CO_2 ownership & liability
- MVA requirements under UIC Class VI
- Varying stakeholder interests
- Right-of-ways

Public Policy (Public Acceptance))

- Identifying stakeholders
- Fostering relationships
- Public perception
- Political challenges
- Injection-induced seismicity

ICKan Project Team

Project Management & Coordination, Geological Characterization

Kansas Geological Survey
University of Kansas
Lawrence, KS
Tandis Bidgoli, PI, Assistant Scientist
Lynn Watney, Senior Scientific Fellow
Eugene Holubnyak, Research Scientist
K. David Newell, Associate Scientist
John Doveton, Senior Scientific Fellow
Susan Stover, Outreach Manager
Mina FazelAlavi, Engineering Research Asst.
John Victorine, Research Asst., Programming
Jennifer Hollenbah - CO2 Programs Manager

Improved Hydrocarbon Recovery, LLC
Lawrence, KS
Martin Dubois, Joint-PI, Project Manager

CO2 Source Assessments, Capture & Transportation, Economic Feasibility

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Houston, TX
Krish Krishnamurthy, Head of Group R&D
Kevin Watts, Dir. O&G Business Development

Policy Analysis, Public Outreach & Acceptance

Great Plains Institute
Minneapolis, MN
Brendan Jordan, Vice President
Brad Crabtree, V.P. Fossil Energy
Jennifer Christensen, Senior Associate
Dane McFarlane, Senior Research Analysist

Energy, Environmental, Regulatory, & Business Law & Contracts

Depew Gillen Rathbun & McInteer, LC
Wichita, KS
Christopher Steincamp, Attorney at Law
Joseph Schremmer - Attorney at Law

Project Partners & Representatives

CO2 Sources

Westar Energy

Brad Loveless, Exec. Director Environ. Services

Dan Wilkus, Director - Air Programs

Mark Gettys, Business Manager

Kansas City Board of Public Utilities

Ingrid Seltzer, Director of Environmental Services

Sunflower Electric Power Corporation

Clare Gustin, V.P. Member Services & Ext. Affairs

CHS, Inc. (McPherson Refinery)

Richard K. Leicht, Vice President of Refining

Rick Johnson, Vice President of Refining

Regulatory

Kansas Department of Health & Environment

Division of Environment

John W. Mitchell, Director

Bureau of Air

Rick Brunetti, Director

Kansas Oil & Gas Operators

Blake Production Company, Inc.

(Davis Ranch and John Creek fields)

Austin Vernon, Vice President

Knighton Oil Company, Inc.

(John Creek Field)

Earl M. Knighton, Jr., President

Casillas Petroleum Corp.

(Pleasant Prairie Field)

Chris K. Carson, V.P. Geology and Exploration

Berexco, LLC

(Wellington, Cutter, and other O&G fields)

Dana Wreath, Vice President

Stroke of Luck Energy & Exploration, LLC

(Leach & Newberry fields)

Ken Walker, Operator

Storage Site Evaluations: Methodological Approach

Reservoir seals
Characterize primary and secondary seals

Fault reactivation & induced seismicity*
Map faults, characterize stresses, fault slip and dilation tendency analysis

Wellbore risk
Evaluate existing and plugged well construction, plugging records, and estimate risk

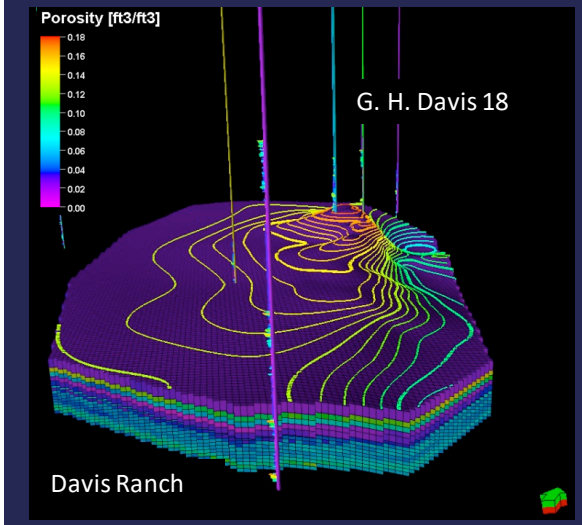
3D cellular geologic model
Utilize existing well and engineering data, 3D seismic, to build cellular static models

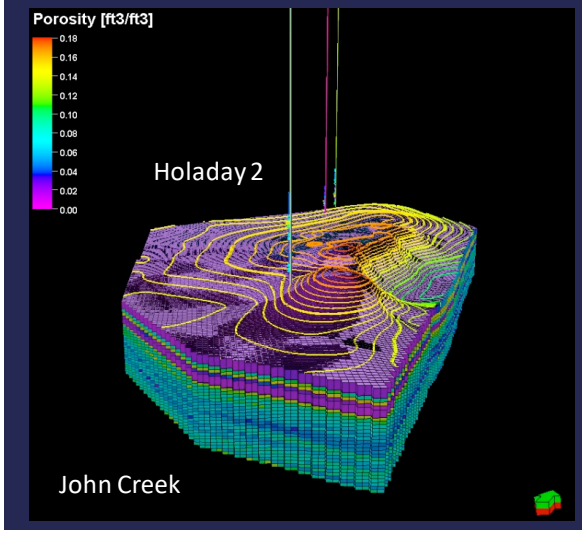
Reservoir simulation model
Use a compositional simulator to analyze capacity, injection rates, and pressure constrained by reservoir seal, fault and seismicity risk, and wellbore risk studies

*Induced seismicity risks for CO2-EOR sites are significantly lower

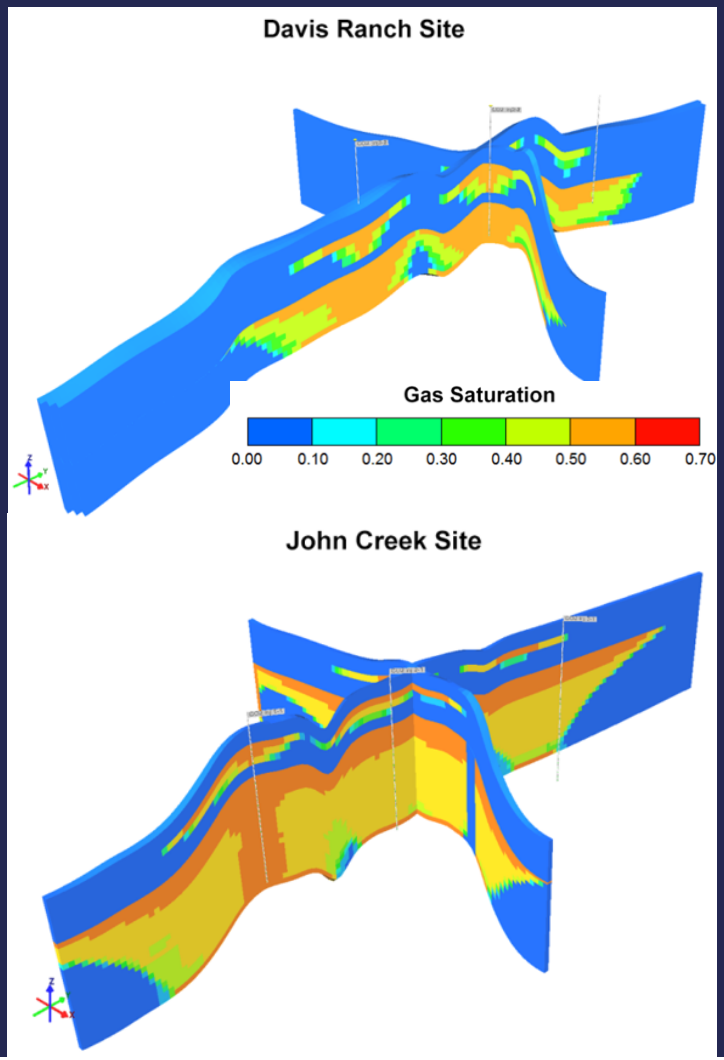
Storage Site Evaluations: Davis Ranch & John Creek

Static 3D cellular models: Porosity & permeability in 3100-3400 ft-deep res.





Dynamic models: analyze injectivity and storage capacity in Simpson and Arbuckle

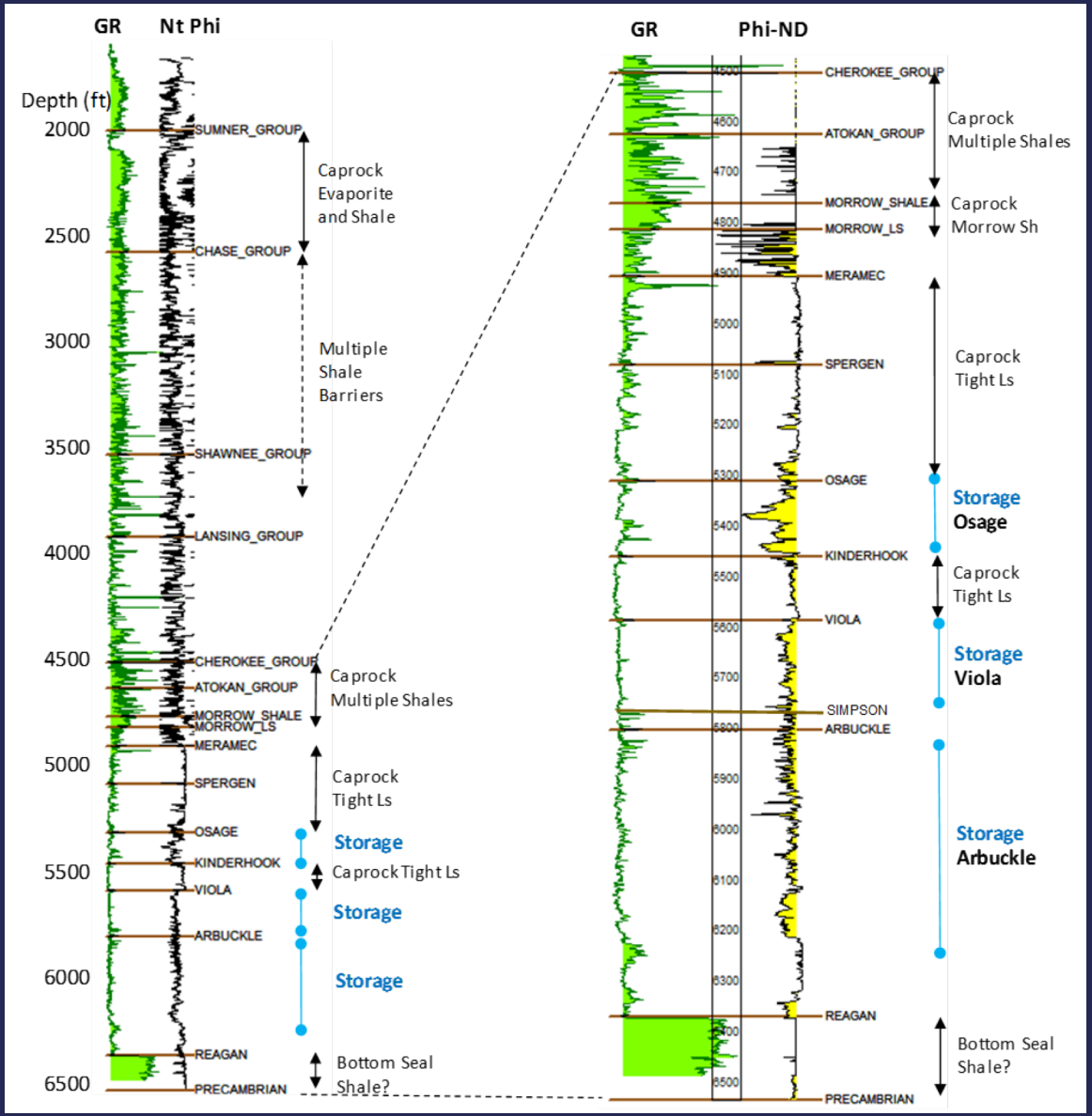


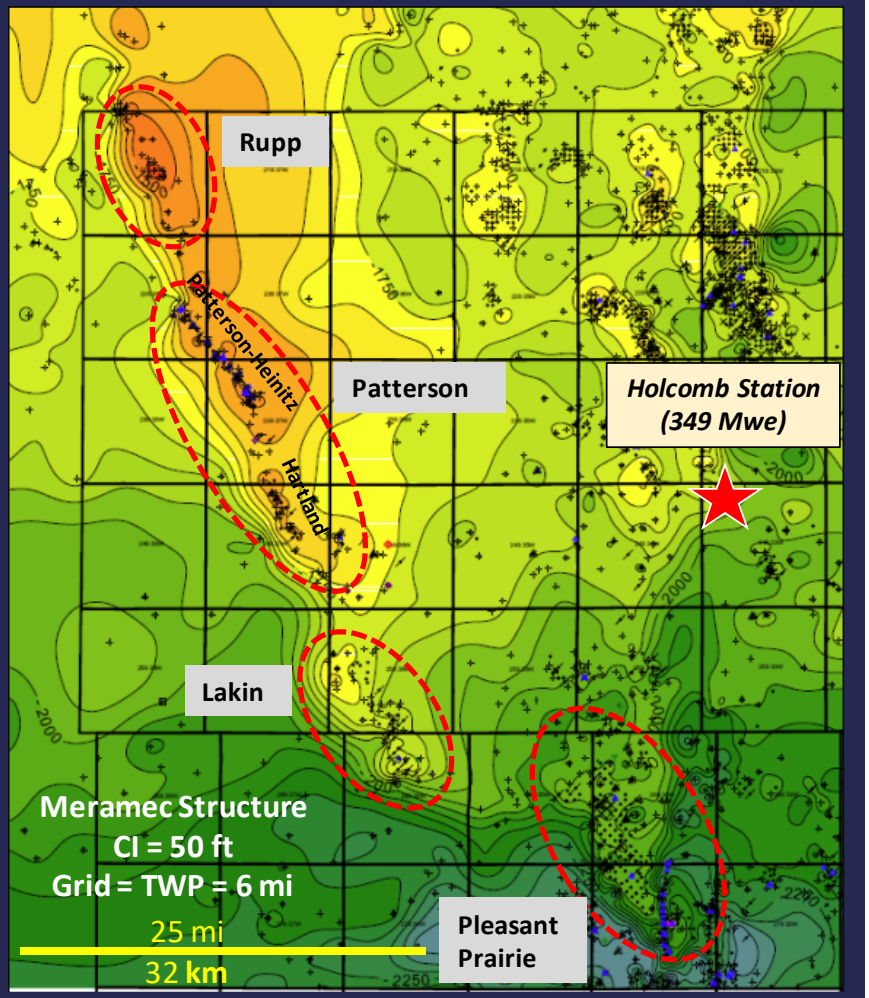
Two largest fields in FCB, located ten miles apart 40-50 miles SW of JEC

Results:

- ✓ Injected for 25 years
- ✓ Combined injection rates: 2350 to 4000 tonnes/day
- ✓ Storage: 24.6 million tonnes
- ✓ Injection rate satisfactory
- ✓ Storage is half the 50 Mt target

Storage Site Evaluations: North Hugoton Storage Complex





- BHP 1650-1750 psi
- BHT 130-135F

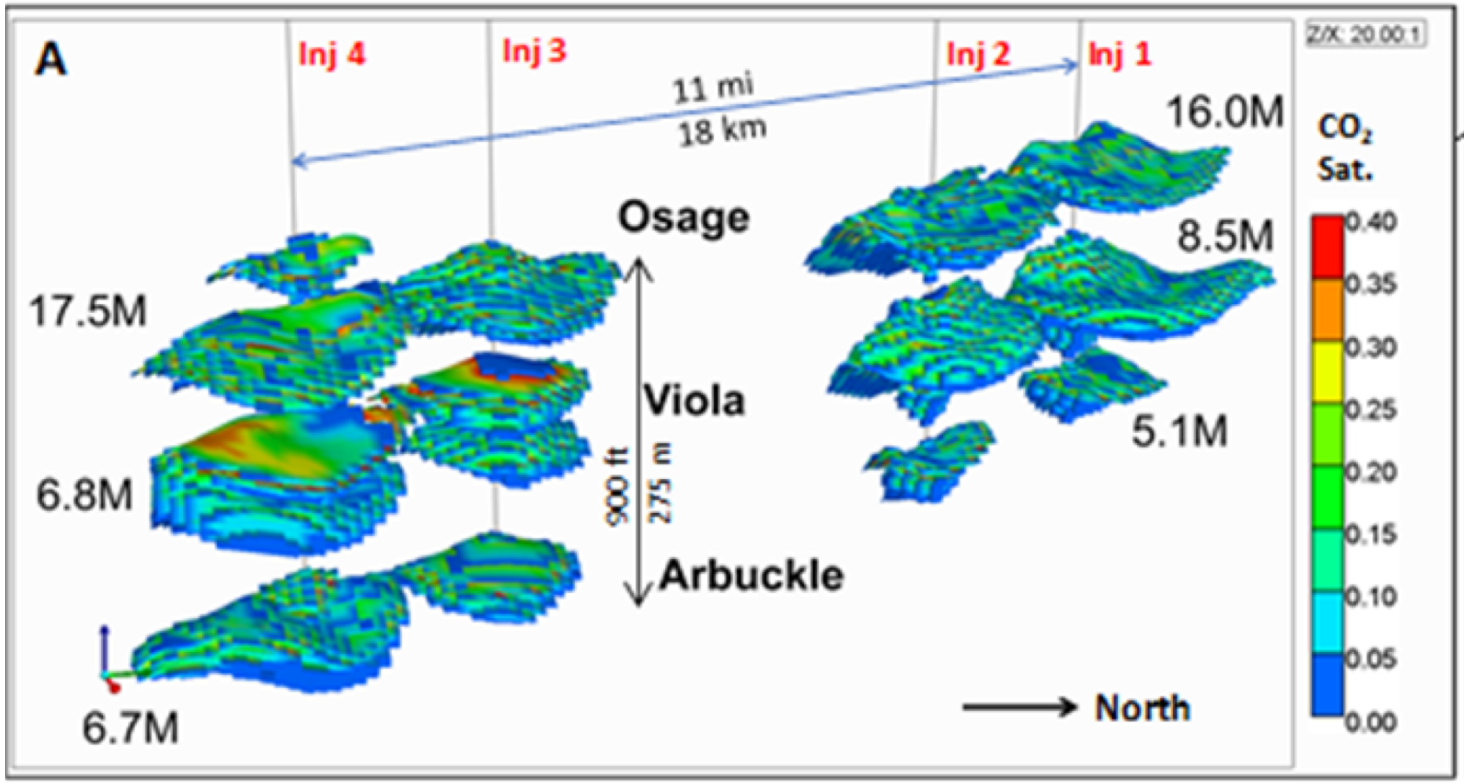
Storage Site Evaluations: Patterson-Heinitz-Hartland Fields

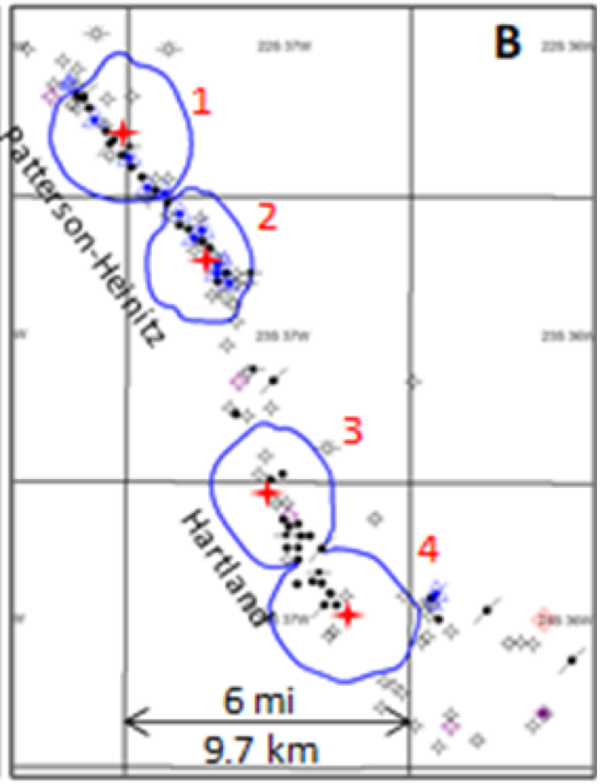
Static 3D cellular model:

- Few wells penetrate saline storage zones (21 wells total)
- Properties established from limited core and injection test

Initial simulation:

- ✓ Inject 5,800 metric tonnes/day
- ✓ 60.6 Mt in 30 yrs
- ✓ Four wells, three zones
- ✓ Additional work to optimize injection





CO_2 Sources

Jeffrey Energy Center, St. Marys, KS

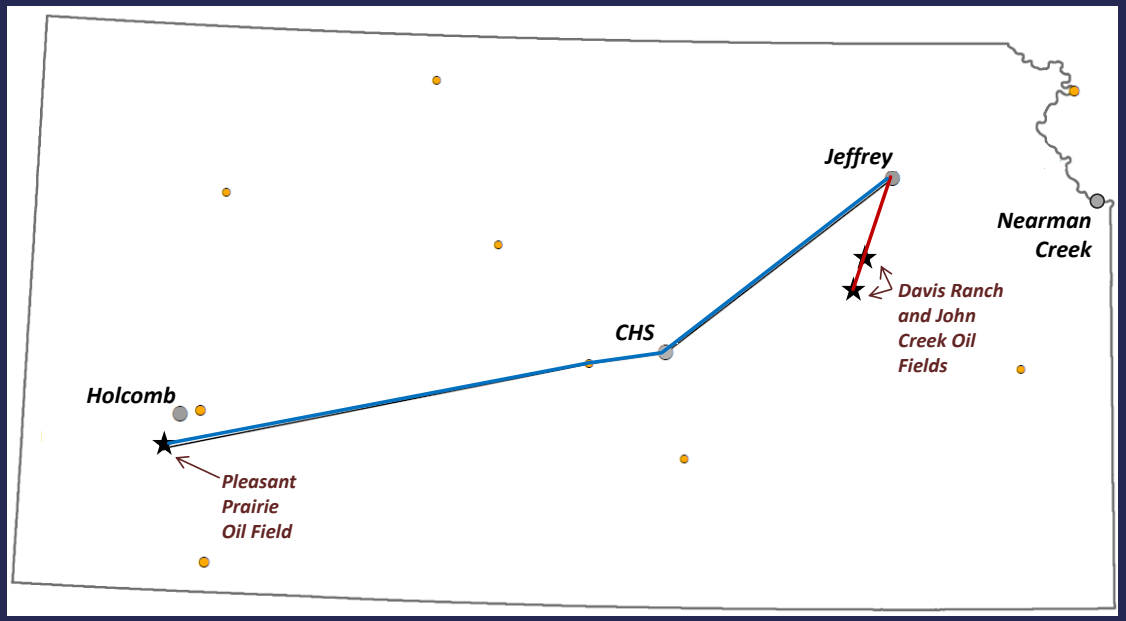
- 3x 800 MWe plants with annual CO_2 emissions of 12.5 million tonnes
- Partial capture of flue gas (~350 Mwe) can meet needs over 20 years
- Optimize: waste heat

CHS Refinery at McPherson, KS

- Flue gas: ~760,000 tonnes/yr (30% of the project needs)
- Solvent-based post-combustion capture process
  - 90% reduction in CO2 emissions
- Optimization via centralized steam generation possible

CO2 Transportation Assessment

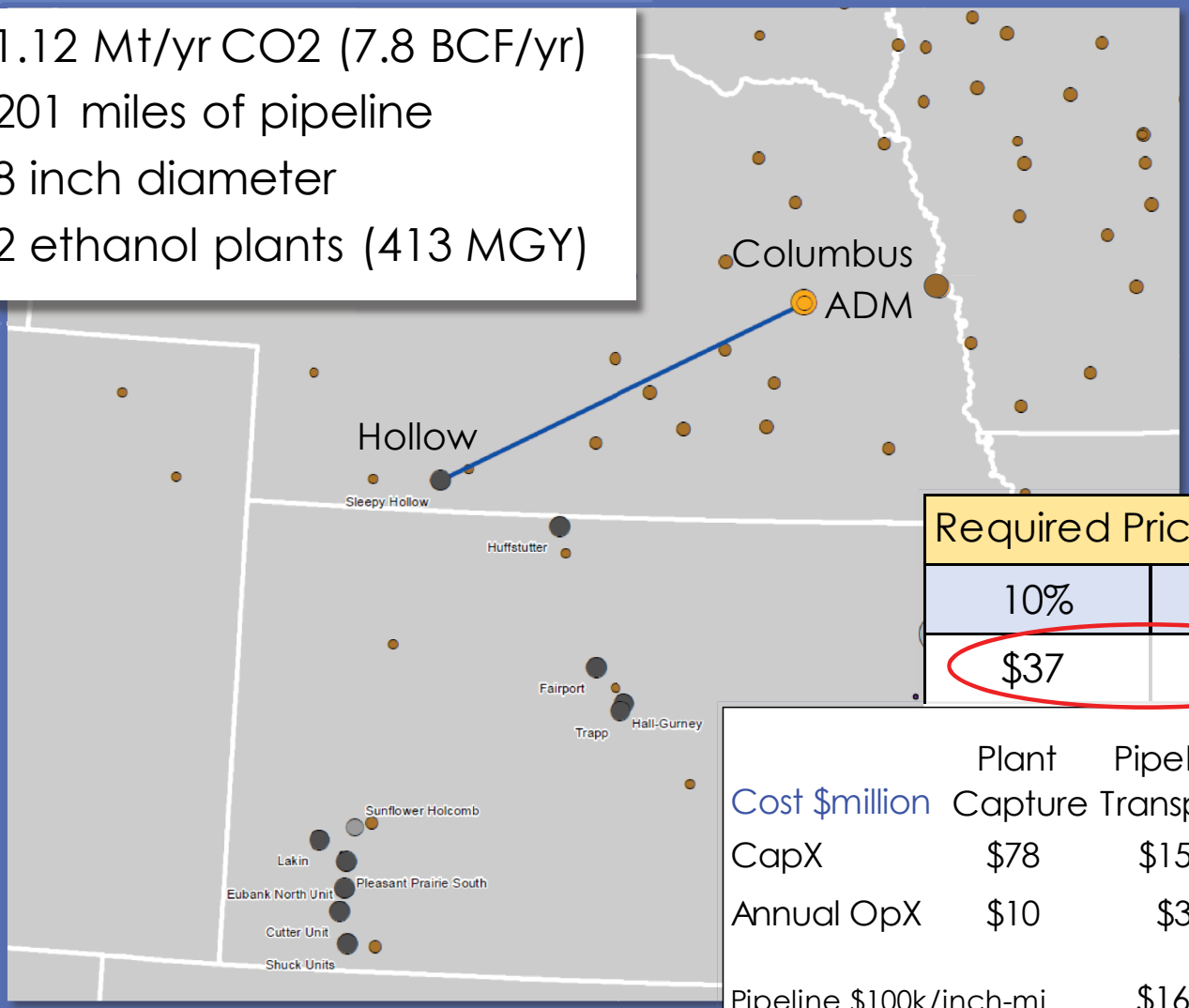
- Modified FE/NETL CO_2 Transport Cost Model (Grant & Morgan, 2014)
- 7 inputs (e.g., length, pumps, capacity, pressures, etc.)
- 12 outputs, including CapEx and OpEx



	Scenario	Distance (mi)	Distance (mi) X 1.2	Volume (MT/yr)	Size (inches)	CapEx ($M)	Annual OpEx ($M)
Jeffrey to MidCon Trunk	**part of 1**	151	181	2.5	12"	$164	$3.8
Jeffrey to Davis Ranch and John Creek	**2**	42	51	2.5*	12" & 8"	$47	$1.3
Jeffrey to CHS and Pleasant Prairie	**3**	294	353	3.25**	12"	$323	$8.0
Jeffrey to Pleasant Prairie	**4**	294	353	2.5	12"	$322	$7.2

Transportation Scenarios: Large point-to-point

- ✓ 1.12 Mt/yr CO2 (7.8 BCF/yr)
- ✓ 201 miles of pipeline
- ✓ 8 inch diameter
- ✓ 2 ethanol plants (413 MGY)



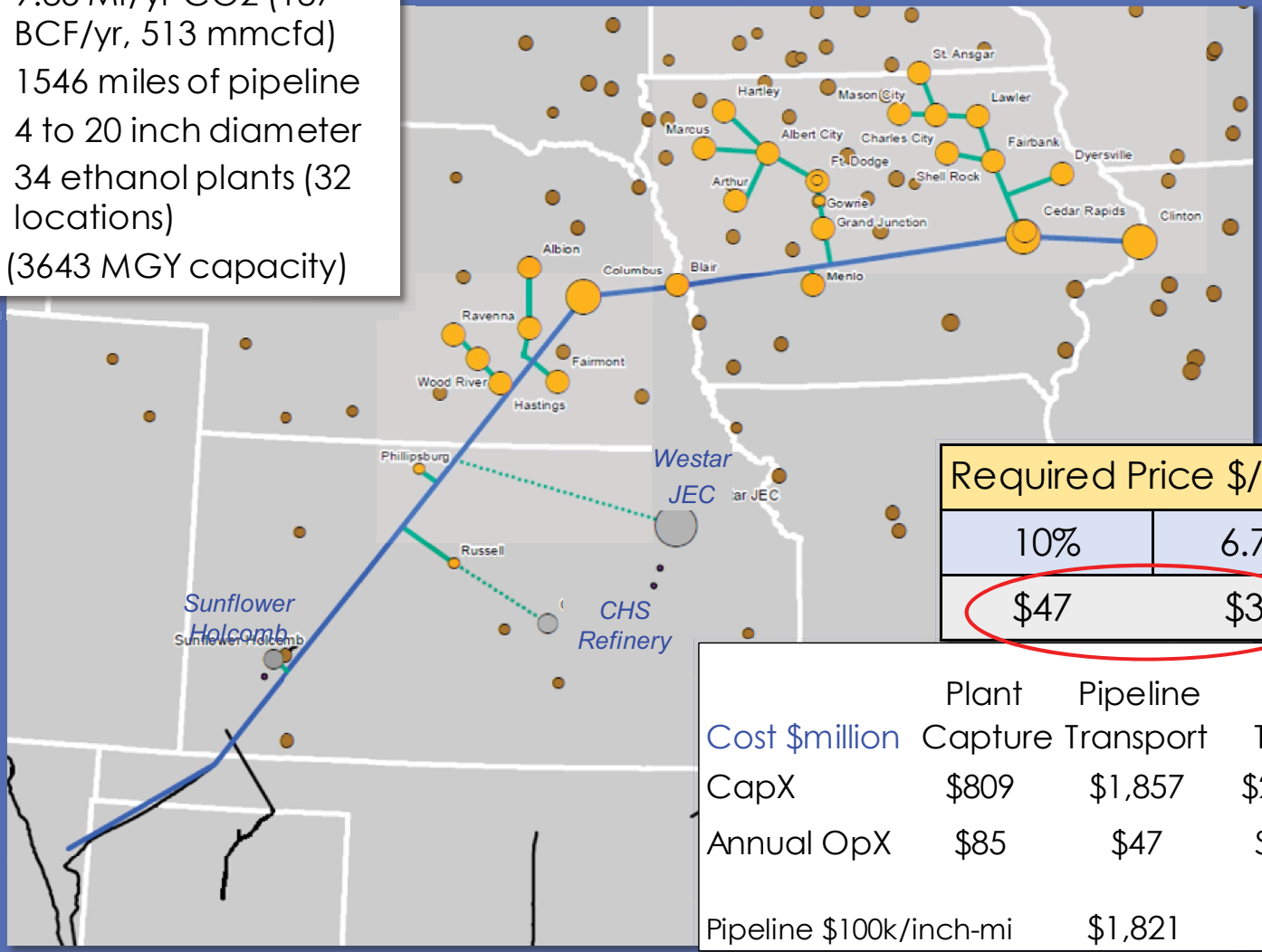
Required Price $/tonne	
10%	6.7%
$37	$31

Cost $million	Plant Capture	Pipeline Transport	Total
CapX	$78	$154	$232
Annual OpX	$10	$3	$13
Pipeline $100k/inch-mi		$161	

Transportation Scenarios: Large-scale capture, 10 Mt/yr

- ✓ 9.85 Mt/yr CO2 (187 BCF/yr, 513 mmcfd)
- ✓ 1546 miles of pipeline
- ✓ 4 to 20 inch diameter
- ✓ 34 ethanol plants (32 locations)

(3643 MGY capacity)



Required Price $/tonne	
10%	6.7%
$47	$39

Cost $million	Plant Capture	Pipeline Transport	Total
CapX	$809	$1,857	$2,667
Annual OpX	$85	$47	$131
Pipeline $100k/inch-mi		$1,821	

White paper

- Multi-state group that launched in 2016
- Working to expand carbon capture, utilization, and storage
- Critical to passage of 45Q

http://www.betterenergy.org/blog/capturing-utilizing-co2-ethanol-adding-economic-value-jobs-rural-economies-communities-reducing-emissions/

Capturing and Utilizing CO_2 from Ethanol:
Adding Economic Value and Jobs to Rural Economies and Communities While Reducing Emissions

White paper prepared by the
State CO_2-EOR Deployment Work Group

December 2017

Remaining work & next steps

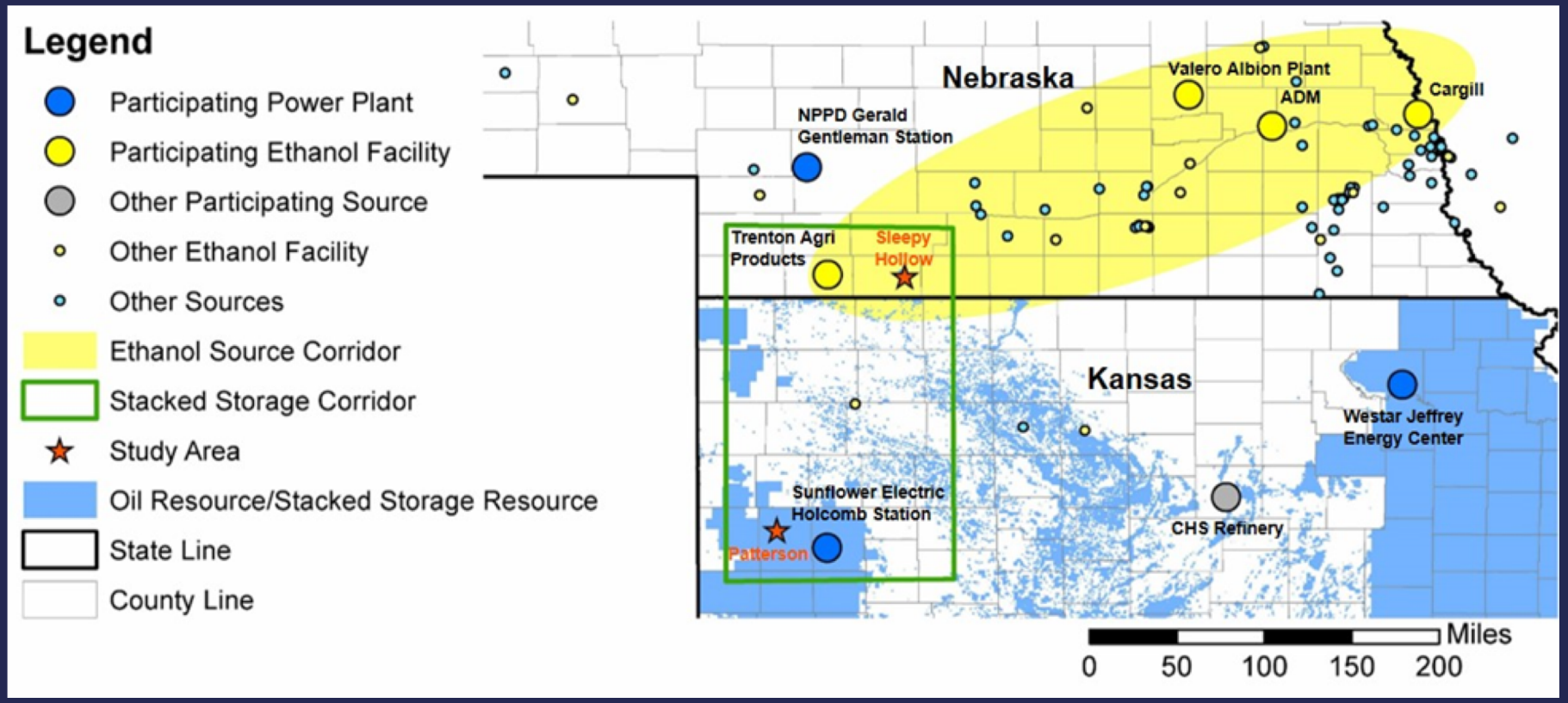
- Economic analysis of integrated project
  - Capture and compression, transportation, and storage site preparation and operations
  - Implications of 45Q tax credit
- Development of an implementation plan
- Phase II application submitted
  - Battelle, KGS, and EERC

CO2 price for 6.7% ROR

	Pipeline	Ethanol	Total
CapX ($/T)	$17.92	$7.81	$25.73
OpX ($/T)	$4.77	$8.58	$13.35
Total ($/T)	$22.69	$16.39	$39.08
Total ($/mcf)	$1.19	$0.86	$2.06
With 45Q			
Total ($/T)	$5.00	$8.68	$13.68
Total ($/mcf)	$0.26	$0.46	$0.72

Current CO2 value = $22.80/tonne ($1.20/mcf)

"Midcontinent Stacked Carbon Storage Hub"



Agency	NGO/Association	Ethanol Producer	Electric Utility	Oil Producer	Other
KS Gov. Colyer	Clean Air Task Force	ADM	NPPD	Berexco	ION Engineering
NE Ethanol Board	Great Plains Institute	Cargill	Westar Energy	Merit Energy	MV Purchasing
NE Dept. of Agriculture	Kansas Independent Oil and Gas Association	Trenton Agri Products	Sunflower Electric Power	Great Plains Energy	The Linde Group
NE Dept. of Environmental Quality	NE Petroleum Producers Association	Valero Renewables	Kansas City Board of Public Utilities	Casillas Petroleum	
NE Corn Board	Renew Kansas	Pacific Eth.		Central Operating	
NE Energy Office					

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Graduate students: Andrew Hollenbach and Jeff Jennings

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Disclaimer:

Questions?

CCUS in Kansas Forum, Sept. 2017